

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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REPORT NUMBER 996

COLD WEATHER GOGGLES:

IV. Optimal Density

by

S. M. Luria

Naval Medical Research and Development Command
Research Work Unit M0095.001-1040

Released by:

W. C. Milroy, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

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SUMMARY PAGE

PROBLEM

To determine the most preferred density for sunglasses

FINDINGS

Observers of all age-groups, with both dark and light eyes, preferred sunglasses which on bright days reduced the light level to 300-400 footcandles. Resolution acuity significantly declined with denser sunglasses for the older observers.

APPLICATIONS

These findings are relevant to the specification of optimal characteristics of protective sunglasses for use in Arctic and other bright environments.

ADMINISTRATIVE INFORMATION

This research was conducted under Naval Medical Research and Development Command Work Unit "Protective devices for the eye in cold weather." The report was submitted on 26 January, 1983, approved for release on 3 March, 1983 and designated as NavSubMedRschLab Rep. No. 996.

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ABSTRACT

Light- and dark-eyed observers, ranging in age from 17 to 67, compared six pairs of sunglasses whose neutral density filters transmitted either 0.8, 2.5, 4.8, 8.9, 15.8, or 91.2% of the light. The sunglasses were worn in bright sunlight both in summer and winter and rated for comfort as to the light-level which they admitted to the eyes. In addition, the observers took a test of resolution acuity with each pair of filters. Observers of both eye-colors and of every age-group preferred, on the average, sunglasses which reduced the light-level to 300-400 footcandles. These preferred filters are much denser than typical commercial sunglasses. Resolution acuity declined significantly for the older observers with filters denser than the preferred ones.

Goggles designed to protect the eyes in cold environments must provide protection against several things. These include the temperature and wind, the bands of harmful radiation (which include the ultraviolet (UV), infrared (IR) and short wavelengths of visible light), and the intensity of the light. Cold environments generally feature snow-covered terrain, and fresh snow reflects around 90% of the incident light. On a bright, sunny day, the intensity of the light in the sky and reflected from the snow may approach values as high as 10,000 footcandles (fc). Even if there were no harmful bands of radiation, the sheer level of intensity would lead to visual discomfort. The question is, to what intensity should the light be reduced?

There has been surprisingly little attention given to this question. Nearly all the work devoted to the problem of the appropriate level of light has centered around three questions. The first is the relationship between light level and visual acuity^{1,2} and the related question of what light level is optimal for various visual tasks.¹ Blackwell³ has concluded that for tasks requiring very acute vision, very high levels are required; for example, he states that inspectors looking for stains on colored cloth may require more than 10,000 fc. These investigations were not, however, concerned with whether or not the specified light levels are also comfortable for extended periods of time.

A second area of investigation has focused on the damage to the

eye by light. These studies have shown that specific bands of radiation are more deleterious than others and that very small amounts of radiation in certain segments of the spectrum can cause damage.⁴ Once again, there is no good correspondence between such dangers and comfort, because, as in the case of sunburn, the damage may be done before the individual feels any discomfort, if, indeed, he ever does.

The third area of investigation has centered on the problem of glare.⁵ These studies have involved small light sources whose intensity is above that of the background to which the observer is adapted, and the measure of visual impairment has typically been some form of acuity. The problem for men in snowfields, however, is not just one of acuity or the elimination of the dangerous bands of radiation or the presence of small glare sources. It is the total illumination. The men may have trouble simply keeping their eyes open for long periods of time in light of uncomfortably high intensity. Thus, we need to know the maximum intensity of ambient illumination which most individuals find comfortable.

There are only a few references which suggest specifications for total transmittance. Some are based on practical experience. Farnsworth⁶ cited a report of an Arctic operation stating that sunglasses which transmitted 12 to 15% of the light were too bright and recommending transmittances of only 4%. He also noted that sunglasses taken from a captured German submarine in 1944 transmitted less than 3% of the light and commented that lookouts on German submarines had been furnished with progressively denser glasses as the war continued.

There are virtually no experimental investigations of the problem. Farnsworth attempted to specify the optimal transmittance by logical analysis. He argued that the problem was to reduce the light level as much as possible without reducing visual efficiency. He proposed that visual efficiency could be defined as the thresholds for visual acuity, brightness discrimination, and chromatic discrimination. The lowest light level which does not result in a reduction of these three functions is the proper level for sunglasses.⁶

A number of studies have shown the relationship between light intensity and visual acuity. Two of the most widely known sets of results are those of Koenig (see Hecht²) and Lythgoe¹. These have shown that there is little improvement in acuity, as measured by standard tests, as the light level rises above 100 fc. In using various performance tests as indicators of the required light level, Blackwell³, as noted above, concluded that illumination as high as 10,000 fc is required for different visual tasks. Nevertheless, reading shorthand written with a No. 3 pencil required only 76 fc, and reading a new micrometer required only 7 fc. It seems unlikely that Marines in the field would require much greater acuity than that.

The definitive work on brightness discrimination was also carried out by Blackwell.⁷ He found that for large stimuli there is no degradation in threshold contrast as adaptation brightness is reduced from 100 to 1 foot-Lambert (fL).*

Finally, the effects of changes in light level on color vision have been reviewed by Ruddock.⁸ He concluded that foveal color matches do not change except near threshold or at very high illumination levels. Farnsworth found that color discrimination was not much affected until the light level was reduced below 2 fL.⁶

From these studies, it appears that sunglasses which result in a light level of 100 fc should not degrade visual performance. Indeed, an office illuminated to this level is considered to be well lit. If we assume that on bright days the mean ambient illumination is 4,000 fc, then 100 fc is 2.5% of that value; it is interesting that the German U-boat sunglasses examined by Farnsworth transmitted 2.5% of the light.

These analyses still do not answer the question as to what density of sunglasses will be preferred in the field. There has been one field study, carried out by Hedblom in the Antarctic.⁹ He obtained preference ratings for 20 types of goggles and sunglasses under three conditions: bright sun on pack ice, overcast sun on snow, and looking at a ship's wake toward the sun. Fifteen of 25 men observed briefly in each condition and their ratings were averaged for the three conditions combined. In a second experiment, Hedblom had 11 "mature officers of good judgment" wear a variety of these glasses for periods of 1 to 8 hours. It is noteworthy that the mean order of preferences for this more extended trial was identical to that of the first experiment.

* Footcandle is a measure of illumination falling on a surface; foot-Lambert is a measure of the light reflected from a surface. They are equivalent for a hypothetical surface reflecting 100% of the light.

When the sunglasses are grouped for similar ratings, there is a relationship between their mean transmittances and the ratings. The most highly preferred group of sunglasses averaged 12% transmittance; the next preferred group averaged 25%; the least preferred group transmitted 70% of the light. Nevertheless, Hedblom himself concluded that the critical factor was the ratio of the infrared to the visible transmittance.

To test his hypothesis, Hedblom viewed a "brief intense illumination" through a filter with a high ratio of IR to visible transmittance and found that he suffered severe ocular distress. This filter, however, also transmitted a high amount of blue and UV light. Hedblom had at his disposal another filter which transmitted a similar amount of UV and blue but blocked the IR. Had he replicated his findings with that filter, it would have been clearer that the IR was producing his symptoms. It is quite possible that a high IR transmittance leads to ocular discomfort, but it is not certain that this is more objectionable than a high visible transmittance.

In any event, the most recent military specifications for sunglasses¹⁰ specify that the transmittance of visible light must be limited to the range 12 to 18%. And the Naval Support Force, Antarctic has adopted sunglasses with a "double gradient"; that is, the top and bottom of the filter are very dense, transmitting about 2% of the visible light while the center of the filter transmits about 13%. Both the far UV and IR are screened out.

It is unlikely, however, that the same density would serve for all observers. In the studies on the effects of glare, it has been reported that the ability to tolerate glare decreases with age.¹¹ It seems reasonable to assume that the same would be true for ambient illumination. Moreover, it has been reported that individuals with brown eyes tolerate intense illumination better than those with blue eyes,¹¹ suggesting that blue-eyed individuals would prefer denser goggles than would brown-eyed individuals.

This study investigated which density of neutral filter was reported to be most comfortable in bright sunlight both in summer and winter immediately after a fresh snowfall. Ratings were obtained from different age-groups and from both dark- and light-eyed observers. In addition, the visual acuity of the subjects was measured through the different filters as they looked toward the bright sky.

METHOD

Materials

Sunglasses - Five neutral density filters, ranging in density from 0.76 to 2.05 were selected. Each one was inserted in a plastic safety goggle. The resulting transmittances were 0.8, 2.5, 4.8, 8.9, and 15.8% corresponding to densities of 2.09, 1.60, 1.32, 1.05, and 0.8. In addition, another pair of goggles was left unfiltered; the clear plastic transmitted 91.2% of the light (N.D.=.04). The clear plastic sides of the goggles were blacked out with masking tape so that there were no distracting light rays from the sides.

Acuity test - A series of clear plastic strips about 3 ft long was prepared on each of which were 20 black Landolt "C's". These were randomly oriented and varied in diameter from 2 to 9 mm. The strip was suspended at a distance of 12 ft from the subjects and was viewed against the sky. The subjects wrote down the orientation of all of the C's which they could discern.

Procedure

Sessions were held between the hours of 1:30 and 2:30 PM during the latter half of July and early August and again in December and January after new snowfalls. Every day except one was a bright sunny day; during the summer one session was run on a hazy day, because it seemed to be as bright and uncomfortable as the sunny days. The results obtained on this day were indistinguishable from those on the sunny days. During each session, the brightness of the sky (and the snow) were repeatedly measured with a Gossen light meter. The readings ranged from 3100 to 4100 fc during the summer and 5000 to 8000 fc in the winter.

During each session six subjects were tested, one from each of the six groups. That is, in each session there were two subjects from each of the three age-groups, one with light and one with dark eyes. Each subject wore the six pairs of goggles in a counterbalanced order. The subjects sat side by side facing west, but they were instructed to look in all directions, scan the various objects in the field of view, and also read the "acuity chart." Although the purpose of the study was not to measure the

effect of variations in filter density on acuity, this procedure served to ensure that the subjects spent a certain amount of time looking into the bright sky. It also served to give them an additional basis for rating the comfort and effectiveness of the various sunglasses.

The subjects were allowed to wear each pair of sunglasses until they were satisfied with the trial and ready to make their ratings. This took about 10 to 15 minutes. When the last person in the group had made his or her rating, the sunglasses were exchanged for the next pair, a new set of Landolt C's was presented, and the procedure repeated. The subjects rated each of the sunglasses on a scale of 1 to 10 with regard to the comfort of the level of light which the filters transmitted.

During the two winter sessions, the subjects faced predominantly south, but they were again instructed to look around before making their judgments. Again each subject wore the goggles in counterbalanced order.

Subjects

For the summer experiment, 60 volunteers (45 men and 15 women) were selected so that 20 were below the age of 30, 20 were in their 30's, and 20 were at least 40 years of age. In each age-group, 10 subjects had brown eyes and 10 had light eyes (blue, green, or hazel). Most were staff members of the laboratory or military dependents. Table I gives the mean age in each group. The subjects wore their spectacle corrections under their goggles.

For the winter experiment, 12 subjects were tested, ranging in age

from 21 to 55; six had light eyes and six had dark eyes. Ten had been subjects in the summer sessions.

Table I. Mean ages of subjects

Age	Light eyes	Dark eyes
Below 30	21.9	22.1
30's	36.2	34.8
Above 40	50.2	50.9

RESULTS

The mean ratings given each of the sunglasses in the summer were very similar for the six groups of subjects. Four of the groups gave their highest mean rating to the 1.05 filter ($T=8.9\%$); the dark-eyed 30-year-olds rated the 1.60 filter ($T=2.5\%$) most highly, and the light-eyed 40-year-olds rated the 1.32 filter ($T=5\%$) most highly (see Table II). All but 9 of the 60 subjects preferred a filter in the 1.05 to 1.60 range ($T=8.9$ to 2.5%). Five preferred the 2.09 filter ($T=0.8\%$), and four preferred the 0.8 filter ($T=15.8\%$); these subjects were distributed among all three age-groups; five had dark eyes.

Figure 1 shows the mean ratings for each of the six groups. An analysis of variance of mixed design showed that the ratings were significantly different ($p < .01$) for the different sunglasses, but there were no other significant effects. According to the Tukey

test for differences between means, there were no significant differences between the ratings assigned to the 1.05, 1.32, and 1.60 filters ($T=8.9$, 4.8 , and 2.5%). However, the ratings given to the 2.09 and 0.8 filters ($T=0.8$ and 15.8%) were significantly different ($p < .01$) from the 1.05 filter ($T=8.9\%$). Needless to say, the ratings given to the clear filter were very significantly different from those given to all the other filters.

Table 2. The filter density which was rated most comfortable by each of the groups

Age	Light eyes	Dark eyes
Below 30	1.05	1.05
30-39	1.05	1.60
50 & above	1.32	1.05

Figure 2 gives the mean diameters of the Landolt C's which could be resolved by the subjects of different ages through the different sunglasses. There were virtually no differences between sunglasses for the youngest age-group. For the intermediate group, acuity tended to be better for the intermediate filters. For the oldest group, acuity was distinctly better for the 1.05 filter and worst for the 2.09 filter. An analysis of variance showed that acuity was significantly different ($p < .01$) through the different glasses, and there was a significant difference ($p < .01$) between the acuity scores for the different age-groups. The

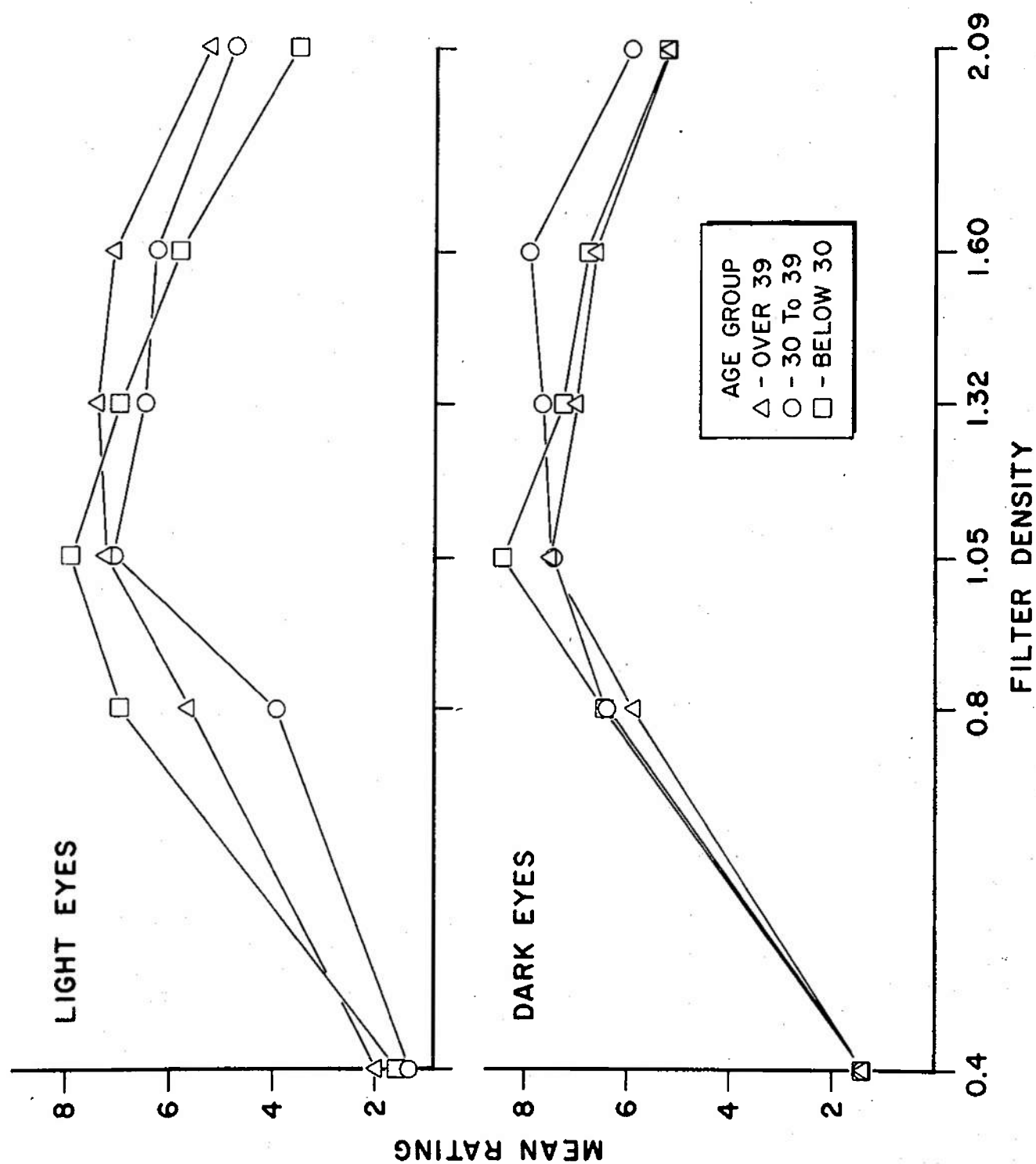


Fig. 1. Mean ratings given to the various filters

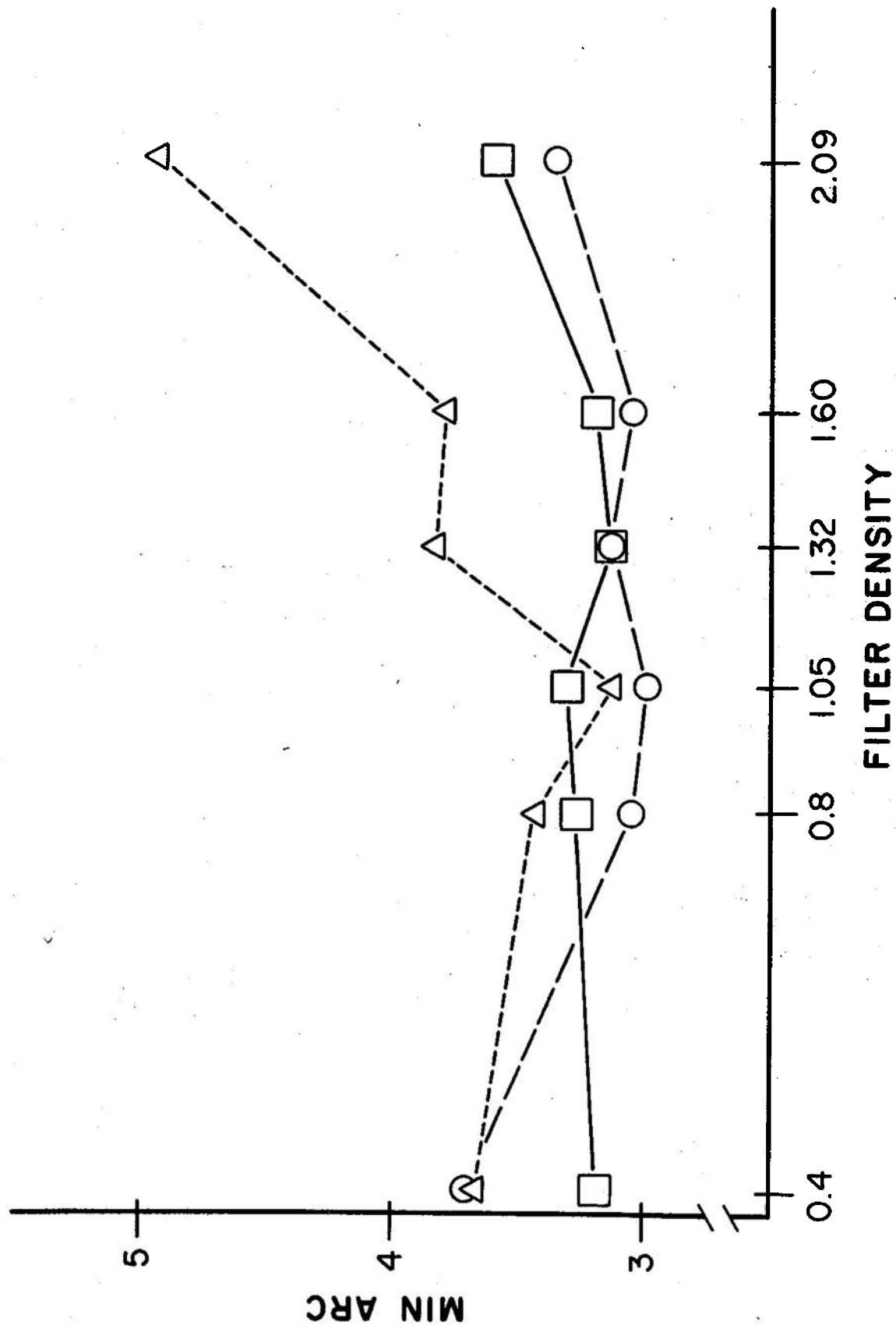


Fig. 2. Mean diameter of the Landolt C's resolved through the various filters by the three age groups (\square below 30; \circ 30-39; Δ over 39)

Tukey test showed that the oldest age-group suffered a significant ($p < .01$) loss of acuity through the densest filter; acuity through the 2.09 filter was much worse than through any of the other filters. Moreover, acuity through the 1.05 filter was significantly better ($p < .05$) than through any of the denser filters. For the other two age-groups, however, there were no significant differences in acuity from one sunglass to another, although mean acuity was best for both groups through an intermediate filter.

In winter, the most highly rated filter was the 1.3 density ($T=4.8\%$) with a mean rating of 8.0. The 1.05 ($T=8.9\%$) and 1.6 ($T=2.5\%$) filters received mean ratings of 7.0 and 6.8, and, as before, the other filters were much less preferred.

DISCUSSION

The density of sunglasses most preferred by these groups of subjects ranged from 1.05 to 1.60 ($T=8.9$ to 2.5%): the 0.8 and 2.09 density filters were rated significantly lower. There is no evidence that the older subjects preferred denser glasses. The light-eyed subjects did give increasingly higher ratings to the denser glasses with increased age, but this was not the case for the dark-eyed individuals; and the ratings for the two groups were not significantly different. Nevertheless, the oldest subjects did suffer a significant loss of acuity with the denser filters even though this was not reflected in their comfort ratings.

It should be noted that 9 of the observers, 15% of the sample,

preferred filters which were darker or lighter than 1.05 to 1.60 density range. In view of this, it would probably be advisable to provide a range of filters from which individuals could choose.

These results lead to two major conclusions. First, they confirm the supposition by Farnsworth that typical sunglasses are too light. The preferred density range of 1.05 to 1.60 is considerably darker than the filters usually found in commercial sunglasses. Figure 3 gives the distribution of densities of 50 pairs of sunglasses found in a local shop. About half of them were made with polarizing filters, but the densities of only 15 of the polarizing filters were measured since it was soon obvious that none of them was very dense: they ranged from .4 to .6 ($T=40$ to 25%). Most of the measurements were made of the non-polarizing glasses. Most of these had a density of 0.7 ($T=20\%$). Only one pair could be found which had a density greater than 1.0 ($T=10\%$). Virtually all of the glasses, then, are lighter than those preferred by the subjects in this study.

The second conclusion is that there is a preferred light level. As the ambient intensity rises, denser filters are preferred. In the summer when the maximum intensity of the sky behind the acuity targets which the subjects were scrutinizing was about 4,000 fc, the preferred filter was 1.0. In the winter when the light levels were 5,000 to 8,000 fc, the preferred density increased to 1.3. In both cases, the ambient illumination was reduced to about 300 to 400 fc.*

* The ranges 4,000 to 8,000 and perhaps even 300 to 400 may seem wide, but it must be kept in mind that the

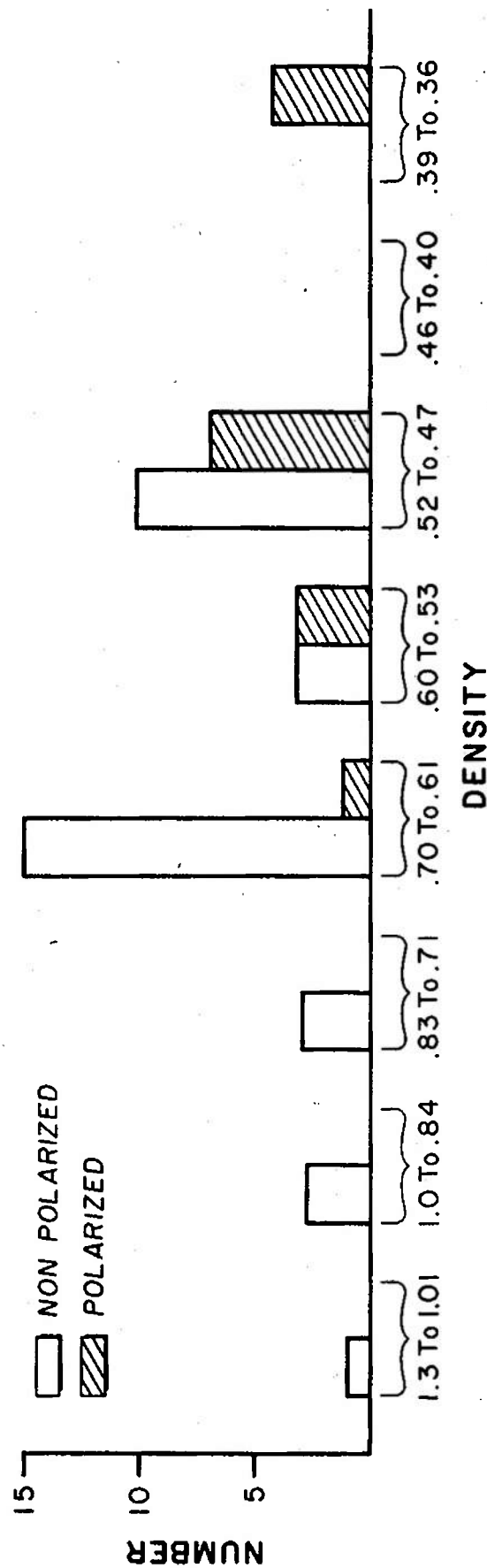


Fig. 3. Distribution of densities measured for a sample of 50 commercial sunglasses

The practical significance of this finding is that it indicates that the optimal density of sunglasses can be specified, since the intensity of the light is known for a given latitude. The preferred densities obtained in this study probably hold for winter and summer conditions everywhere in the world at about the latitude of the northern United States. For other regions, other filters may be best, but given the measurement of the light levels, they can be specified.

These results supplement previous investigations specifying the degree to which specific bands of spectral radiation, known to be hazardous to the eye, must be filtered out without regard to subjective comfort.¹²

visual system is so constructed that differences in intensity are not perceived as being important until they begin to approach a log unit-- that is, a factor of 10. The change in intensity from 5,000 to 8,000 fc measured with the light meter in different directions on the snow were not perceived as being particularly great. The difference between 300 and 400 fc is hardly noticeable.

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